GAMMA-RAY LARGE AREA SPACE TELESCOPE (GLAST) PROJECT

MISSION SYSTEM SPECIFICATION

APRIL 24, 2001

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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(GLAST)
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NASA Goddard Space Flight Center

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GLAST PROJECT MISSION SYSTEM SPECIFICATION

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GLAST PROJECT MISSION SYSTEM SPECIFICATION

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Acronyms

b	bit
B	Byte
CCSDS	Consultative Committee for Space Data Systems
DN	Data Number
DL	Downlink
EU	Engineering Units
FITS	Flexible Image Transport System
Gb	Gigabit
GCN	Gamma Ray Burst Coordinates Network
GLAST	Gamma ray Large Area Space Telescope
GN	Ground Network
GOF	Guest Observer Facility
GPS	Global Positioning System
HEASARC	High Energy Astrophysics Science Archive Research Center
IOC	Instrument Operations Center
MB	Megabyte
MOC	Mission Operations Center
PB	Playback
RT	Real Time
SC	Spacecraft
SI	Science Instrument
SN	Space Network
SSC	Science Support Center
SSR	Solid State Recorder
TBD	To Be Determined
TBS	To Be Supplied
TBR	To Be Resolved
TDRSS	Tracking and Data Relay Satellite System
UL	Uplink

1 Introduction

1.1 Purpose and Scope

This document responds to the Level 1 requirements for the Gamma-ray Large Area Space Telescope (GLAST) mission. It also responds to the system architectural requirements of the Announcement of Opportunity for GLAST, to the science requirements that are given in the Science Requirements Document, and to the operations concept that is described in the Operations Concept Document for the mission. Implementation of these of requirements is accomplished in this document by defining the operational system that acquires the science data and by specifying the top-level requirements of the different elements of that system. These system requirements together with the requirements for the system elements and their interfaces constitute the level 2 requirements for the mission.

This document is structured according to the functional hierarchy for the system. This hierarchy extends down from the overall system to the major systems that are to be developed, namely, the observatory system and the ground system. Interface requirements are also developed for the launch vehicle and for the space-ground link.

1.2 System Architecture

The GLAST system is shown in hierarchical form in the architecture block diagram of Figure 1-1. The overall system is comprised of 3 segments. The flight segment includes the launch vehicle and the observatory, which consists of payload instruments and spacecraft. The ground segment is comprised of all of the operating centers and the communications networks that connect them. The space-ground segment consists of the systems that connect flight and ground segments. This architecture also provides the structure for the organization of this specification.

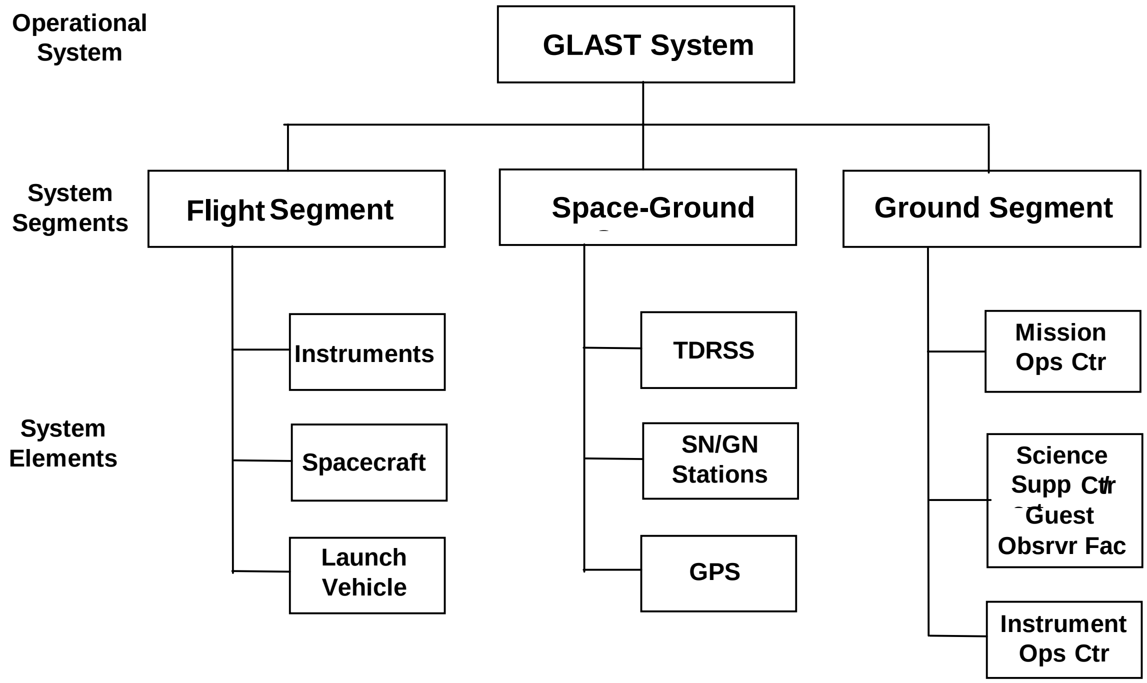


Figure 1-1 Architectural Block Diagram of the GLAST System

1.3 Flow Down Methodology

The purpose of flow down of a system requirement is to ensure that a requirement is recognized and addressed by a subsystem. Some requirements decompose; others do not. Requirements that do not compose flow down from system to subsystem by restatement, where the system requirement is restated in terms of the subsystem. System general requirements that are common to two or more subsystems are handled in this manner.
Requirements that do decompose are assigned at the system level to subsystems that implement the different aspects of the system requirement.

1.4 Definitions

The following definitions provide the meanings for the terms as they are used in this document.
Acceptance Stage: Period during which the deliverable flight item is shown to meet functional, performance, and design requirements under conditions specified for the mission.

Analysis (A): Predicted performance using calculations to show compliance with specified performance.

Autonomy: Performed without ground intervention.

Data Corruption: Probability of an undetected error in a block of data.

Demonstration (D): Observed compliance of functional operation or behavior with that specified.

Degradation: Reduction in the ability of an instrument to acquire data. This may be due to loss of performance, such as increased noise causing loss of sensitivity; or it may be due to partial loss of functionality that results from loss of some, but not all, channels of the same kind.

Development Stage: Prior to the manufacturing of flight hardware.

Disposal Stage: The period during which disposal requirements are verified.

Failure: Loss of functionality, i.e., the loss of the ability to perform a function, at any level (part, component, system).

Investigator: A GLAST investigator is any scientist who is authorized to use the GLAST system for the acquisition and analysis of data.

Inspection (I): Visual proof of existence of specified characteristics or properties.

Jitter: Unwanted high-frequency motion (outside the control bandwidth of the attitude control system) of the instrument line of sight. If the line of sight moves during an "exposure," or CCD integration time, the image is smeared. Jitter is most meaningfully specified in terms of peak-to-peak angular variation and time duration. The time interval of interest is the integration time of the detector, and the peak-to-peak angle requirement is bounded by the amount of image smearing that is acceptable for science.

LAT Central Field of View: Defined as within 30 degrees of the +Z axis.

Latency: Age of the oldest data in an acquisition period.

Measurement: Comparison of data against a scale.

Mode: A specific configuration and set of operations or behavior that accomplish a given purpose.

Observation: Acquisition of data without evaluation against a measurement scale.

Observing Efficiency: Fraction of time available that is spent acquiring data. On this mission the time available is the time on orbit less down time in the South Atlantic Anomaly.

Operational Verification Stage: Post launch period in which the flight system is verified to operate in space environment conditions and in which requirements demanding space environment are verified.

Pointed Observation: Observation in a commanded direction for a commanded duration.

Pointing Direction: The direction of a normal to the LAT reference surface, which in general may be a curved surface.

Pointing Accuracy: Difference between commanded (desired) direction and actual direction, comprised of control error, c, plus measurement error, k. See diagram below.

Pointing Knowledge: Difference between actual direction and the (measurement) estimate. See diagram below.

Qualification Stage: Period during which the flight or flight-type item is shown to meet functional, performance, and design requirements under conditions more severe than acceptance conditions.

Redundant: Availability of more than one path or method for accomplishing a given function.

Reliability: Probability that at least the essential components have survived at the end of design life. For spacecraft components, it is usually fairly clear what is essential. For example, if you have 2 of anything, like batteries, transponders, etc., and you lose both of them, the mission is over. For instrument components, where there are multiple redundancies, what is essential is determined by what data the customer is willing to pay for in continued operations.

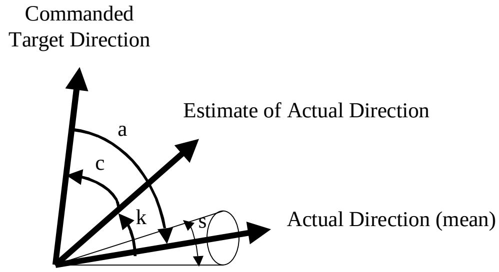
Repoint Observation: An interruption of an on-going scan or pointed observation to temporarily observe a transient target.

Scan Observation: Continuous rotation of the pointing direction about the orbit normal.

Test (T): Measurement of performance to show compliance with specified performance.

Verification: The process of proving that the implementation satisfies the requirement. The central question is whether the system is built right. The methods of showing compliance with requirements are Inspection, Demonstration, Analysis and Test, as defined above.

Pointing Error Definitions



s = Stability (peak to peak motion)
a = Pointing Accuracy (long term)
c = Control Error
k = Knowledge Error

2 Applicable Documents

GLAST Level 1 Requirements Document, TBS

GLAST Science Requirements Document, September 2000

GLAST Operations Concept Document, September 2000

Announcement of Opportunity, Gamma Ray Large Area Space Telescope (GLAST) Flight Investigations, NASA AO 99-OSS-03, March 1999

Delta II Payload Planners Guide: http://www.boeing.com/defense-space/space/delta/delta2/guidelines.htm

CCSDS 701.0–B–1, “Recommendation for Space Data Systems Standards. Advanced Orbiting Systems, Networks, and Data Links: Architectural Specification.” CCSDS Recommendation, Blue Book, October 1989.

CCSDS 202.0–B–2, “Recommendation for Space Data Systems Standards. Telecommand, Part 2: Data Routing Service.” CCSDS Recommendation, Blue Book, October 1989.

CCSDS 101.0-B-3 "Recommendation for Space Data Systems Standards. Packet Telemetry Channel Coding." CCSDS Recommendation, Blue Book.

CCSDS 201.0-B-2 "Recommendation for Space Data Systems Standards. Packet Telecommand, Part 1: Channel Service." CCSDS Recommendation, Blue Book.

CCSDS 201.0-B-1 "Recommendation for Space Data Systems Standards. Packet Telecommand, Part 2.1: Command Operation Procedures." CCSDS Recommendation, Blue Book.

NSS 1740.14, NASA Safety Standard, Guidelines and Assessment Procedures for Limiting Orbital Debris, August 1995.

GEVS-SE Rev A. General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components. http://arioch.gsfc.nasa.gov/302/gevs-se/toc.htm

NPD 8010.2C, NASA Policy Directive, Use of the Metric System of Measurement in NASA Programs.

NPD 2810.1, NASA Policy Directive, Security of Information Technology, October 1998.

NPD 2820.1, NASA Policy Directive, NASA Software Policies, May 1998.

NPD 8610.7, NASA Policy Directive, Launch Services Risk Mitigation Policy for NASA-Owned Or NASA-Sponsored Payloads, February 4, 1999.

3 Requirements

3.1 System Requirements

System requirements are the requirements that are common to all system elements.

3.1.1 General Requirements

General requirements are requirements that do not decompose. They flow down from system to subsystems by identical restatement.

3.1.1.1 Launch Date

The design, development, and operational readiness of the GLAST system shall meet the launch date specified on the master schedule for the project.

3.1.1.2 Lifetime

3.1.1.2.1 In-Orbit Checkout Period

The in-orbit checkout period shall be up to 60 days.

3.1.1.2.2 Operational Lifetime

The operational lifetime of the GLAST system shall be a minimum of 5 years, with a goal of 10 years, following an initial period of in–orbit checkout.

3.1.1.2.3 Orbital Lifetime

The orbital lifetime shall not exceed 25 years beyond the operational lifetime as required by NSS 1740.14.

3.1.1.3 Disposal Method

At the end of mission life, the method of disposal shall be by controlled reentry into the Earth's atmosphere for safe ocean disposal.

3.1.1.4 Orbit

The initial orbit altitude shall be 550 km.
Orbit inclination shall be equal to or less than 28.5 degrees.
Initial orbit eccentricity shall be less than 0.01, as provided by the launch vehicle for circular orbit.

3.1.1.5 Communications

3.1.1.5.1 Space-Ground Communications

The GLAST system shall use two paths for space-ground communications, a direct ground path, and a relay satellite path.

3.1.1.5.1.1 Direct Ground Path

The direct ground path shall provide the services to communicate the data types at the rates and center frequencies given in Table 1:

Data Type	Comm. Mode	Rate, kbps/ Mbps	X-band return, GHz	S-band forward, GHz	S-band return, GHz
Science		150 M	TBD (≈ 8)		
Command	GN	2 k		TBD (2.025 - 2.120)	
Telemetry, real time	GN	≤ 32 k (TBR)			TBD (2.100 - 2.300)
Telemetry, playback	GN	≤ 2.5 M (TBR)			TBD (2.100 - 2.300)

Table 1. Rates and Frequencies for Direct Link

3.1.1.5.1.2 Relay Satellite (TDRSS) Path

The relay satellite path shall provide the services to communicate the data types at the rates and center frequencies given in Table 2:

Data Type	Comm. Mode/ Service	Rate, Kbps/ Mbps	S-band forward, GHz	S-band return, GHz
Command/ Software Loads	SN/SSA	4 K	TBD (2.025 - 2.120)	
Telemetry, real time	SN/SSA	1 K		TBD (2.100 - 2.300)
Target of Opportunity	SN/SMA	1 K	2.1064	
Alerts	SN/SMA	1 K		2.2875

Table 2. Rates and Frequencies for TDRSS Link

3.1.1.5.1.3 Orbit-Average Science Data Rate

The GLAST system shall be designed to accommodate an orbit-average science data rate of 300 kbps with a goal of 1 Mbps.

3.1.1.5.1.4 Telemetry Contacts

The GLAST system shall accommodate telemetry contacts that provide up to 36 hours of science and housekeeping data at the orbit-average data rates.

3.1.1.5.1.5 Grade of Service

Space-ground communications for GLAST shall implement Grade-2 service as defined in the CCSDS Recommendation for Advanced Orbiting Systems.

3.1.1.5.1.6 System Bit Error Rate

The GLAST end-to-end system shall use communication links (RF, land line) that provide an uncoded bit error rate of 10-5 or less.

3.1.1.6 Coordinate Systems

GLAST shall use the J2000 inertial coordinate system, using Right Ascension (RA) and Declination (DEC), as a standard means of identifying and reporting celestial objects and of communicating pointing directions among its systems.

3.1.1.7 Data Standards

GLAST shall employ the recommendations of the Consultative Committee on Space Data Systems (CCSDS) for the transport of its data throughout the system.

3.1.1.8 Units of Measurement

GLAST shall observe the current NASA policy directive, NPD 8010.2C, Use of the Metric System of Measurement in NASA programs.
Metric units shall be used with the following exceptions: Angular measure may be expressed in degrees, minutes, and seconds; Photon and particle energy may be expressed in eV; and English units may be used for mechanical fabrication.

3.1.2 System Operability Requirements

3.1.2.1 Observation Plans

The GLAST system shall carry out the observation plans of GLAST investigators.

3.1.2.2 Observation Modes

The GLAST system shall acquire science data in 2 basic observation modes, sky survey mode and pointed observation mode, and a repoint mode.

3.1.2.3 Targets of Opportunity

The GLAST system shall accommodate requests submitted by the scientific community to observe targets of opportunity.

3.1.2.4 Transient Event Response

The GLAST system shall respond to gamma-ray bursts and other transient events that are detected on board in either mode of observation.

3.1.2.4.1 Alert Transmission

The GLAST system shall automatically transmit an alert message of a transient event to other observatories.

3.1.2.4.2 Repointing

The GLAST system shall be capable of repointing the observatory to observe qualified gamma-ray bursts.

3.1.2.5 Data Handling

3.1.2.5.1 Packets

3.1.2.5.1.1 Variable Length

The GLAST system shall accommodate variable-length source packets for both science and housekeeping data.

3.1.2.5.1.2 Packetized Events

Source packets for gamma-ray events shall be constructed with one or more events.

3.1.2.5.1.3 Ancillary Data

Source data packets for science data shall be constructed to contain the ancillary data from the spacecraft that is necessary for stand-alone processing of the packets on the ground. (Calibration and alignment data will be constructed separately from science data sets.)

3.1.2.5.1.4 Packet Identifiers

The GLAST system shall implement unique packet identifiers for each of the different sources of data (LAT, GBM, SC).

3.1.2.5.2 VCDU Service

The GLAST system shall implement the multiplexed virtual channel data unit (VCDU) service of the CCSDS Advanced Orbiting Systems Architectural Specification.

3.1.2.6 Validated Science Data

The GLAST system shall provide validated science data to the GLAST user community.

3.1.3 System Maintainability Requirements

3.1.3.1 Fault Handling Capability

The GLAST system shall provide the capability for resolving flight hardware and software faults and anomalies.

3.1.3.2 Engineering Mode

The GLAST system shall provide an engineering mode to accommodate the following operations during the course of the mission.

3.1.3.2.1 Adaptable Detection Algorithms

The GLAST system shall accommodate adaptable detection algorithms (for the LAT) during on-orbit operations.

3.1.3.2.2 Unfiltered LAT Science Data

The GLAST system shall accommodate LAT unfiltered data.

3.1.3.2.3 Calibration

The GLAST system shall perform calibration observations as required during the course of the mission.

3.1.3.2.4 System Checkout and Test On Orbit

The GLAST system shall support system checkout and tests in different on/off and operational configurations of observatory system components.

3.1.4 System Allocations

3.1.4.1 Alert Response Time

The alert response time shall be less than 7 seconds with a goal of less than 4 seconds from the time of spacecraft receipt of GRB notification from GBM or LAT to delivery to the Gamma-ray Coordinates Network (GCN) computer for 80% of all GRBs detected by the GBM or LAT.
The alert response time shall be met with the following allocations:

3.1.4.1.1 Alert Acquisition and Initiation of Transmission

The spacecraft shall initiate transmission of an alert message within 1 second of detection of a GRB by either science instrument.

3.1.4.1.2 Alert Transmission

The space-ground link shall transmit alert messages to its ground station in less than 5 seconds.

3.1.4.1.3 Ground Interface to GCN

The ground system shall transfer the alert message from the ground station to the GCN within 1 second.

3.1.4.2 Observing Efficiency

The GLAST system shall achieve an observing efficiency of at least 90 % with a goal of 95 %.

3.1.4.2.1 Degradations

3.1.4.2.1.1 Pointing Knowledge

Pointing knowledge shall remain within the knowledge allocation during all slews of the observatory in its normal observing modes.

3.1.4.2.1.2 Telemetry Transmission

Telemetry transmissions shall not degrade the on-going acquisition of science data.

3.1.4.2.1.3 Observing Plans

At least 2 observing plans (the current plan plus a backup) shall be available to the MOC for implementation at all times during the pointed observation phase of the mission.

3.1.4.2.2 Viewing Interruptions

3.1.4.2.2.1 Outages

The total time spent in outages that prevent acquisition of science data, i.e., those that result in safe mode, shall not exceed 1 % (TBR) of the operational life of the mission.

3.1.4.2.2.2 Default Procedures

Observing plans shall include default procedures that avoid having the earth enter the central field of view of the LAT.

3.1.4.2.3 Data Loss

The total data loss of less than 2 % with a goal of less than 1 % in the data delivery part of the GLAST system shall be met with the following allocations:

3.1.4.2.3.1 Malfunction

The data loss allocated to malfunctions that occur in the science data flow and that prevent delivery of acquired data (without incurring safe mode) shall not exceed 0.1 % (TBR) of mission science data.

3.1.4.2.3.2 Operator Error

The data loss allocated to operator error shall not exceed 1.5 % (TBR) of mission science data.

3.1.4.2.3.3 System Unavailability

The data loss allocated to system unavailability (downtime that causes a set of contacts to be missed) shall not exceed 0.1 % (TBR) of mission science data.

3.1.4.2.3.4 Transmission Losses

The data loss allocated to lost packets and errors that are tolerated in the space-ground downlink without retransmissions shall not exceed 0.2 % (TBR) of mission science data.

3.1.4.3 Data Corruption

The probability of an undetected bit error in each LAT event data block shall be < 10-10 with a goal of 3 x 10-11.

3.1.4.3.1 Encoding

The LAT shall encode event data packets for end-to-end error detection at the specified level of probability of undetected bit error based on the maximum block length and an assumed system bit error rate of 10-8.

3.1.4.3.2 Decoding

The LIOC shall perform error detection on LAT-encoded event data blocks to screen the data blocks for bit errors.

3.1.4.4 Data Latency

The maximum data latency shall not exceed 120 hours.
The system data latency shall be less than 72 hours 95% of the time. This is allocated as follows:

3.1.4.4.1 On Board Storage Latency

The on board storage data latency for science data shall not exceed 36 hours.

3.1.4.4.2 Downlink and Transmission Latency

The data latency for downlink and transmission of science data to IOC and MOC shall not exceed 12 hours.

3.1.4.4.3 Start of Production Processing

The production of standard data products by the LIOC shall begin within 24 hours of receipt of data.

3.2 Launch Vehicle Requirements

3.2.1 General Requirements

3.2.1.1 Launch Vehicle Provider

GLAST shall use a U.S. commercial launch vehicle and launch services as required for NASA-related missions by NMI 8610.12C.

3.2.1.2 Launch Date

The launch vehicle shall support a launch readiness date as specified on the master schedule.

3.2.1.3 Baseline Launch Vehicle

For design purposes prior to official selection, the baseline launch vehicle for the GLAST mission shall be the Delta II 2920 with 3 meter fairing and 6915 payload attach fitting.

3.2.1.4 Availability

The launch vehicle shall be available for purchase by NASA for the specified launch date.

3.2.1.5 Reliability

Launch Vehicle reliability shall be 95% or greater at 50% confidence level.

3.2.1.6 Orbit

The launch vehicle shall provide an initial orbit altitude of 550 km.
The launch vehicle shall provide an orbit inclination that is equal to or less than 28.5 degrees.
The launch vehicle shall circularize the initial orbit to an eccentricity that is less than 0.01, as provided by the nominal performance of the launch vehicle.

3.2.2 Performance Requirements

3.2.2.1 Fairing envelope

The launch vehicle shall provide minimum useable fairing dimensions of 2.743 m diameter by 3.15 m height.

3.2.2.2 Throw Capability

The launch vehicle shall place the GLAST observatory in the specified orbit.

3.3 Observatory Requirements

Observatory requirements are the requirements that apply in common to the science instruments and to the spacecraft.

3.3.1 Observatory General Requirements

3.3.1.1 Observatory Launch Date

The observatory shall be designed for an observatory launch date as specified on the master schedule for the project

3.3.1.2 Design Life

The design life of the observatory shall be a minimum of 5 years, with a goal of 10 years, following an initial period of in–orbit checkout.

3.3.1.3 In-Orbit Checkout

3.3.1.3.1 Overall Period

The overall period for in-orbit checkout of the observatory shall not exceed 60 days.

3.3.1.3.2 Initial Phase

An initial period of up to 10 (TBR) days of in-orbit checkout is allocated to the spacecraft with the remainder allocated to the science instruments.

3.3.1.4 Orbit

The initial orbit altitude shall be 550 km.
Orbit inclination shall be equal to or less than 28.5 degrees.
Initial orbit eccentricity shall be less than 0.01, as provided by the launch vehicle.

3.3.1.5 Observatory Reliability

3.3.1.5.1 Credible Failures

Except for structural assemblies, including pressure vessels, no credible single point failure shall jeopardize the mission.
No two credible failures shall cause loss of life or damage to surrounding facilities (transporters, launch pads, launch vehicle, etc.

3.3.1.5.2 Observatory Reliability

The GLAST observatory shall achieve an overall mission reliability of > 70 % at 5 years.

3.3.1.5.2.1 Spacecraft Reliability Allocation

Spacecraft reliability shall be at least 85 % with a goal of 90 % at 5 years.

3.3.1.5.2.2 LAT Reliability Allocation

LAT reliability shall be at least 85 % with a goal of 90 % at 5 years.

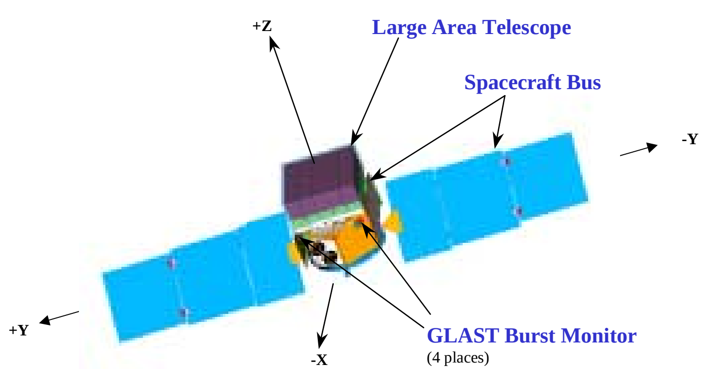
3.3.1.6 Coordinate Systems

3.3.1.6.1 Inertial

The observatory shall use the J2000 inertial coordinate system, using RA and DEC, as a standard means of identifying and reporting celestial objects and of communicating pointing directions between its systems.

3.3.1.6.2 Body Fixed

The observatory shall use the body fixed coordinate system shown in the figure below. The origin is in the separation plane. The + Z axis is normal to the separation plane and is directed upwards through the body of the spacecraft and the LAT instrument. The Y-axis is parallel with the solar array drive axes. The assignment of the + X-axis to a specific side of the spacecraft is TBD.



3.3.1.6.3 Pointing Axis

The axis for pointing direction of the observatory is defined as the +Z axis.

The Z-axis shall be collinear with the geometric centerline of the observatory.

3.3.1.7 Units of Measurement

The observatory shall observe the current NASA policy directive, NPD 8010.2C, Use of the Metric System of Measurement in NASA programs.
The observatory shall use metric units with the following exceptions: Angular measure may be expressed in degrees, minutes, and seconds; Photon and particle energy may be expressed in eV; and English units may be used for mechanical fabrication.

3.3.1.8 Data Standards

The observatory shall employ the recommendations of the Consultative Committee on Space Data Systems (CCSDS) for telemetry and telecommand.

3.3.1.9 Mass Allocations

3.3.1.9.1 Observatory Mass

The total mass of the observatory at launch including fuel shall not exceed 4460 kg.

3.3.1.9.2 Spacecraft Mass

The mass of the spacecraft including contingency shall not exceed 1100 kg.

3.3.1.9.3 Fuel for Reentry

The mass allocated to fuel for reentry is 290 kg.

3.3.1.9.4 LAT Mass

The mass of the LAT including contingency shall not exceed 3000 kg.

3.3.1.9.5 GBM Mass

The mass of the GBM including contingency shall not exceed 70 kg.
The mass allocated to project reserve is 0 kg (TBR).

3.3.1.10 Payload Power Allocations

3.3.1.10.1 LAT Power

The orbit average power for the LAT including contingency shall not exceed 650 W.

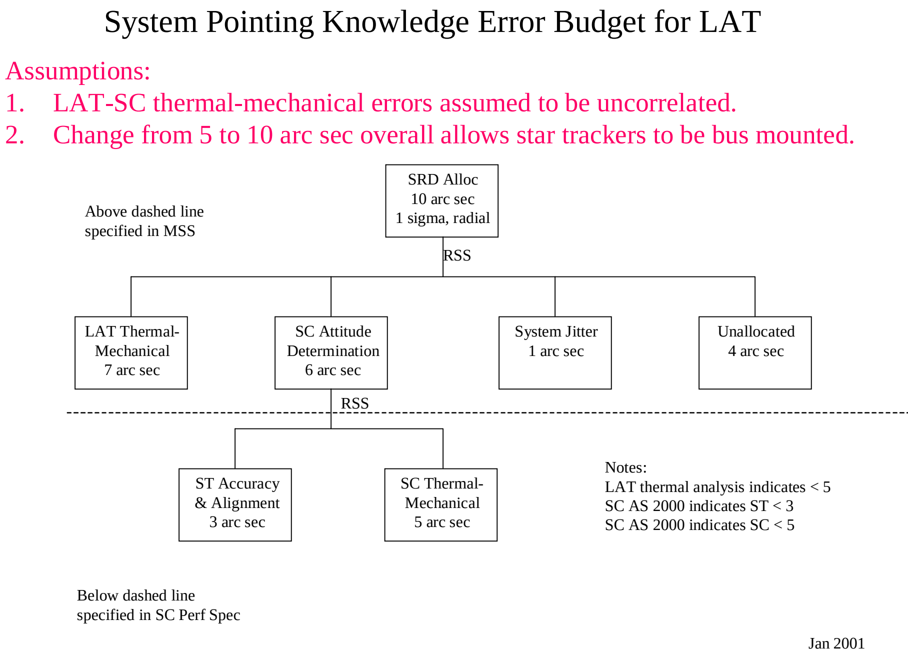
3.3.1.10.2 GBM Power

The orbit average power for the GBM including contingency shall not exceed 50 W.

3.3.1.11 Pointing Knowledge Allocations

3.3.1.11.1 LAT-SC System

A pointing knowledge requirement of 10 arc seconds with a goal of 5 arc seconds, 1 sigma, radius, for the LAT-SC system shall be met by the following end-to-end error budget over the period of **time between on-orbit calibrations** (TBD). These allocations are considered to be uncorrelated errors and are therefore combined in quadrature.



3.3.1.11.1.1 Spacecraft Attitude Determination

Spacecraft attitude determination errors with respect to the LAT interface plane shall be less than 6 arc seconds, 1 σ, radial.

3.3.1.11.1.2 LAT Thermal Mechanical

Thermal-mechanical stability (knowledge) of the LAT reference surface relative to the interface plane shall be less than 7 arc seconds, 1 σ, radial.

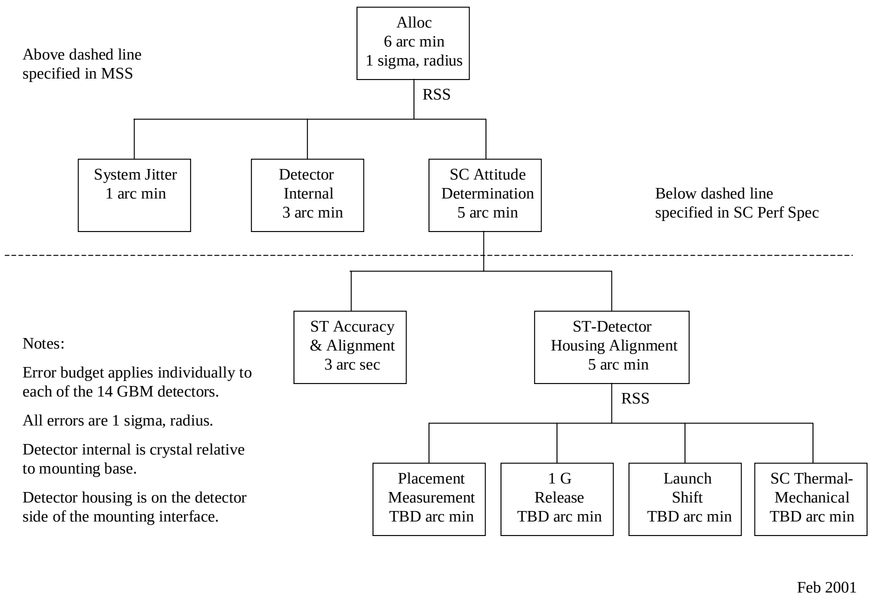
3.3.1.11.1.3 System Structural Dynamics

Structural dynamics errors for the LAT-spacecraft system, including jitter, shall be less than 1 arc second, 1 σ, radial.

3.3.1.11.2 GBM-SC System

A pointing knowledge requirement of 6 arc minutes, 1 sigma, radius, for the GBM-SC system shall be met by the following end-to-end error budget.

System Pointing Knowledge Error Budget for GBM



3.3.1.11.2.1 Spacecraft Attitude Determination

Spacecraft attitude determination errors with respect to the GBM detector mount shall be less than 5 arc minutes, 1 σ, radial.

3.3.1.11.2.2 Detector Internal

Internal misalignment of a detector crystal relative to its housing mount shall be less than 3 arc minutes, 1 σ, radial.

3.3.1.11.2.3 System Structural Dynamics

Structural dynamics errors for the GBM-spacecraft system, including jitter, shall be less than 1 arc minute, 1 σ, radial.

3.3.2 Observatory Functional Requirements

3.3.2.1 General Operational Requirements

3.3.2.1.1 Ground Commanded Repointing

The observatory shall be capable of repointed observations in all modes of observation upon ground command.

3.3.2.1.2 GRB Alert Transmission

The observatory shall transmit GRB alert messages in all modes of observation.

3.3.2.1.3 Sequences of Observations

The observatory shall be capable of executing sequences of pointed and scanning observations from on-board command storage.

3.3.2.1.4 Data Acquisition

The observatory shall be capable of acquiring science data at an orbit average data rate of 300 kbps with a goal of 1 Mbps.

3.3.2.1.5 Data Storage

The observatory shall have the capability to acquire and store up to 36 hours of science and housekeeping data between telemetry contacts.

3.3.2.1.6 Communications

3.3.2.1.6.1 Grade of Service

The observatory shall implement Grade-2 service as defined in the CCSDS Recommendation for Advanced Orbiting Systems.

3.3.2.1.6.2 Ground Network

The observatory shall communicate via the ground network at the rates and frequencies given in table 1.

3.3.2.1.6.3 Space Network

The observatory shall communicate with the ground via the space network at the rates and frequencies given in table 2.

3.3.2.2 Sky Survey Mode

3.3.2.2.1 Zenith Pointed

The +Z axis of the observatory shall be zenith pointed (without "rocking").

3.3.2.2.2 Scan Motion

The +Z axis of the observatory shall rotate about the orbit normal at 1 revolution per orbit.

3.3.2.2.3 Rocking

The observatory shall be capable of "rocking" the +Z axis of the observatory up to 60 degrees above and below the plane of the orbit.

3.3.2.2.4 Sky Coverage

The observatory shall scan the LAT field of view over the full celestial sphere repetitively every 2 (TBR) orbits.

3.3.2.2.5 Data Acquisition

Downlink transmissions of science data shall not degrade the on-going acquisition of science data.

3.3.2.2.6 Downlink Transmission

Downlink transmissions of science data shall not be interrupted by a repointing command from any command source (SI, SC, ground).

3.3.2.2.7 Mode Transitions

Transition to and from sky survey mode shall occur upon real-time ground command or delayed-time stored command.

3.3.2.3 Pointed Observation Mode

The observatory shall have the capability for pointing to a celestial target in either of the following sub modes.

3.3.2.3.1 Target Tracking Sub Mode

The observatory shall maintain the Z-axis to within 30 degrees of a commanded direction.

3.3.2.3.2 Inertial Pointing Sub Mode

The observatory shall maintain the Z-axis to within 2 degree of a commanded direction.

3.3.2.3.3 Downlink Transmissions

3.3.2.3.3.1 Priority

Downlink transmissions of science data in pointed observation mode shall take priority over on-going pointed observations.

3.3.2.3.3.2 Interruption of Pointed Observation

An on-going pointed observation may be interrupted to meet the pointing constraints for downlink transmissions of science data.

3.3.2.3.4 Mode Transitions

Transition to and from pointed observation mode shall occur upon real-time ground command or time-delayed stored command.

3.3.2.4 Repoint Mode

3.3.2.4.1 Autonomous Repointing

The observatory shall be capable of repointing autonomously in either mode of observation in response to GRBs detected on board.

3.3.2.4.2 Go/No-Go Decision Making

The observatory shall be capable of go/no-go decision making in response to on-board repointing commands.

3.3.2.4.3 Automatic Resume

Upon completion of a repointed observation that is performed autonomously, the observatory shall automatically resume the previously interrupted observation (sky survey or pointed observations).

3.3.2.5 Data Handling

3.3.2.5.1 Source Packets

3.3.2.5.1.1 Variable Length

The observatory shall accommodate source data packets for science and housekeeping data with variable length.

3.3.2.5.1.2 Ancillary Data

The observatory shall construct source data packets with ancillary data for stand-alone processing of data packets.

3.3.2.5.1.3 Unique Identifiers

The observatory shall construct source data packets with unique identifiers for each source of data.

3.3.2.5.2 Virtual Channels

The observatory shall organize its data for storage and transmission using different virtual channels for different data types.

3.3.3 Maintainability Requirements

3.3.3.1 Engineering Checkout Mode

3.3.3.1.1 Mode Transitions

Transition in and out of engineering mode shall occur upon ground command.

3.3.3.1.2 Observatory Attitude

In engineering mode, the default attitude shall be zenith pointed (no rocking, no targeting) with yaw steering for sun tracking of solar arrays.

3.3.3.1.3 Housekeeping Data

The observatory shall be capable of reallocating storage and bandwidth to increased housekeeping sampling rates and telemetry transmission rates.

3.3.3.1.4 Software Uploads

The observatory shall be capable of receiving and loading up to 1 MB of LAT or GBM software at a time.

3.3.3.1.5 Unfiltered LAT Data

The observatory shall be capable of acquiring LAT unfiltered science data.

3.3.3.1.6 Real Time Communications

Full-orbit coverage shall be available via S-band communications for real-time telemetry.

3.3.4 Observatory Safety Requirements

3.3.4.1 Autonomous Fault Protection System

The observatory shall perform on-board fault detection and correction for mission-critical control functions where faults will cause damage or loss of control if not corrected immediately.

3.3.4.1.1 Fault Detection

The observatory shall continually monitor its on-orbit operation for faults.

3.3.4.1.2 Fault Isolation

The observatory shall be designed to isolate faults to prevent propagation.

3.3.4.1.3 Fault Response

The observatory shall implement a hierarchical fault response system (retries, one-time component switch, safe mode trigger).

3.3.4.2 Safe Mode Environment

The observatory shall provide a safe mode environment that is thermal and power safe indefinitely.

3.3.4.3 Safe Mode Alert

The observatory shall transmit a safe mode alert message upon entering safe mode.

3.3.5 Observatory System Interfaces

3.3.5.1 Space Environment Performance Requirements

3.3.5.1.1 Radiation Environment

3.3.5.1.1.1 Performance

The observatory shall operate in the space radiation environment, given in section 3.3.6, for the specified orbit and operational lifetime with no loss of functionality or performance capability.

3.3.5.1.1.2 SAA Safeguard

The observatory shall provide a safe configuration to protect itself from charged particle radiation within the boundaries of the SAA.

3.3.5.1.2 Atomic Oxygen Environment

The observatory shall withstand the TBD atomic oxygen environment for the specified orbit and operational lifetime with no loss of functionality or performance capability.

3.3.5.1.3 Micrometeoroid Environment

The observatory shall operate in the micrometeoroid environment, given in section 3.3.6, for the mission orbit and operational lifetime while meeting its reliability requirement.

3.3.5.1.4 Debris Environment

The observatory shall operate in the debris environment, given in section 3.3.6, for the mission orbit and operational lifetime while meeting its reliability requirement.

3.3.5.2 Launch Environment

The observatory shall survive the launch environment (vibration, acoustics, pressure differentials, and temperature), as characterized in the Payload Planners Guide for the specified launch vehicle, with no degradation to its operational capability or performance.

3.3.5.3 Launch Vehicle Constraints

The observatory shall meet the constraints of the launch vehicle (mass, envelope, and location of center of gravity) as defined in the Launch Vehicle Interface Requirements Document.

3.3.5.4 TDRSS Constraint

The observatory shall be compatible with the existing space network (TDRSS).

3.3.5.5 Ground Station Constraint

The observatory shall interface with existing ground stations for direct to ground telemetry of observatory data.

3.3.6 Space Environmental Estimates

This section provides the environmental estimates for the observatory.

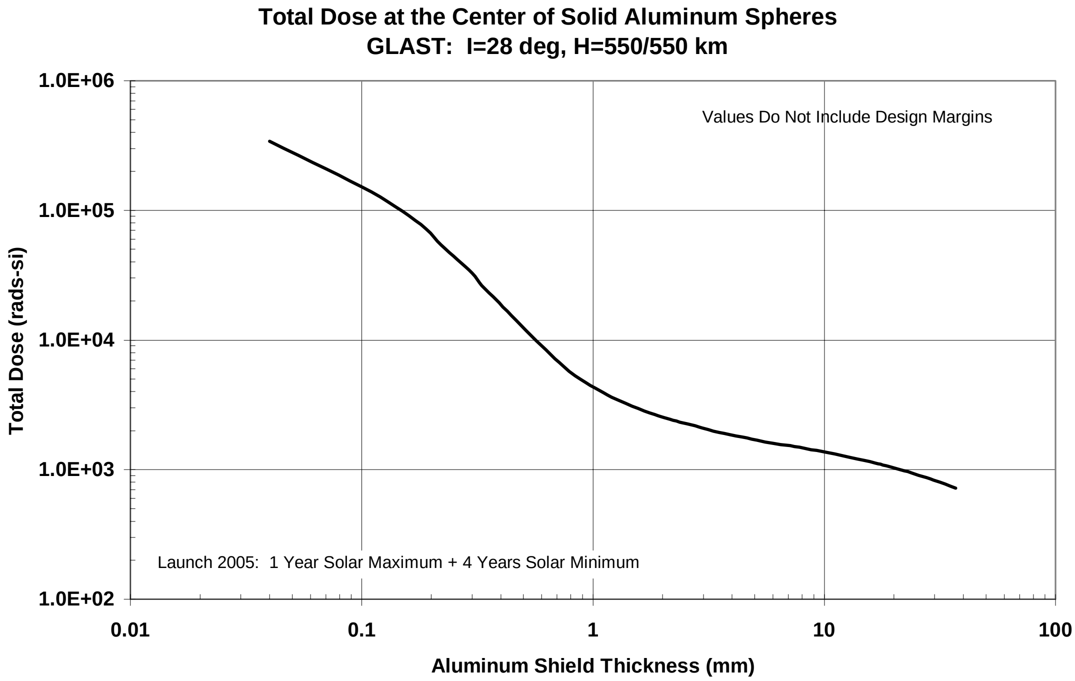
3.3.6.1 Charged Particle Radiation

This section gives the total dose and single event upset (SEU) requirements for the charged particle radiation environment.

3.3.6.1.1 Total Ionizing Dose

Figure 3-9. Total Dose-Depth Curve.

The total ionizing dose for a 5-year mission in the GLAST orbit, beginning in 2005, is given by the dose-depth curve in Figure 3-9.



3.3.6.1.2 Total Dose Design Margin

A multiplicative factor of 2 shall be applied to the total dose estimate for estimate uncertainty, and an additional factor of 2.5 shall be applied to achieve an overall design margin of 5. Shielding shall be designed and parts chosen to yield the required design margin.

3.3.6.1.3 LET Spectrum

The LET energy spectrum for direct ionization by heavy ions is given in Figure 3-10.

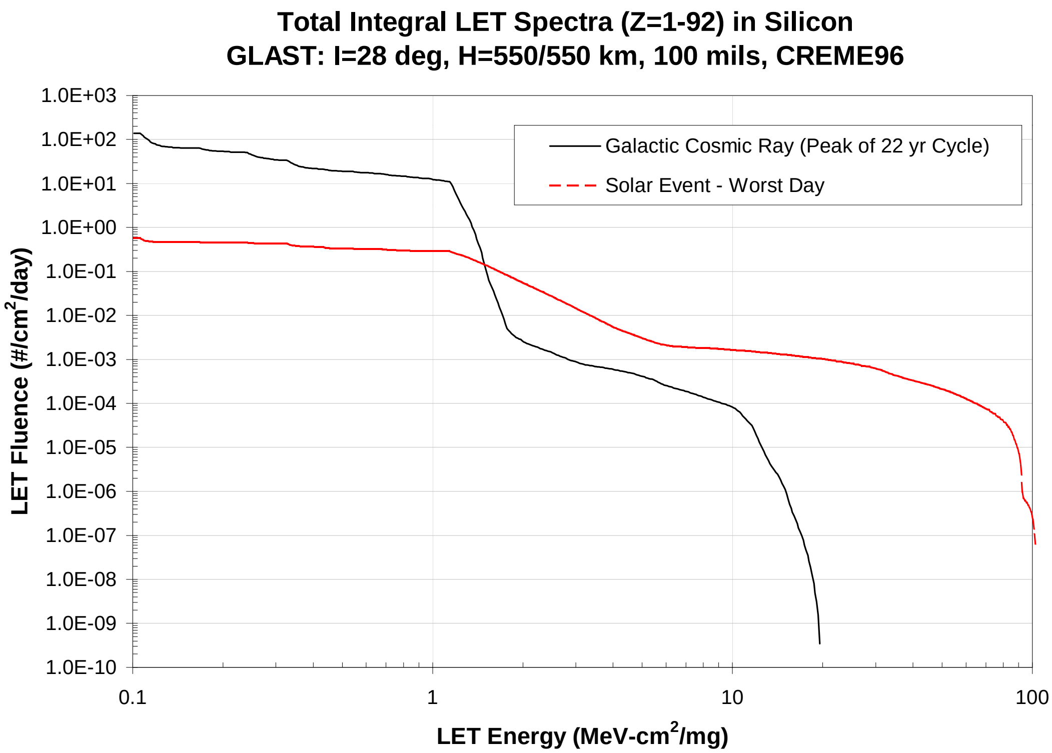


Figure 3-10. LET Spectra.

3.3.6.1.4 Single Event Effects Immunity

Electronic parts shall be selected for tolerance to single event effects as follows.

3.3.6.1.4.1 LET Guideline

A linear energy threshold of 8 MeV/mg/cm^2 (TBR) shall be used as a guideline to select parts for reasonably low probability (TBD) to single event upset due to proton induced secondaries.

3.3.6.1.4.2 SEL Immunity

Electronic parts shall be selected for immunity to single event latch-up.

3.3.6.2 Meteoroid and Debris Flux

3.3.6.2.1 Meteoroid Flux

Figure 3-11 gives the meteoroid flux at 550 km. The meteoroid environment encompasses only particles of natural origin. The average mass density for all meteoroids is 0.5 grams (g) per cubic centimeter, and the average velocity for all meteoroids is 20 kilometers per second. The meteoroid flux is from the NASA SSP-30425 (1991) model that can be found at http://envnet.gsfc.nasa.gov.

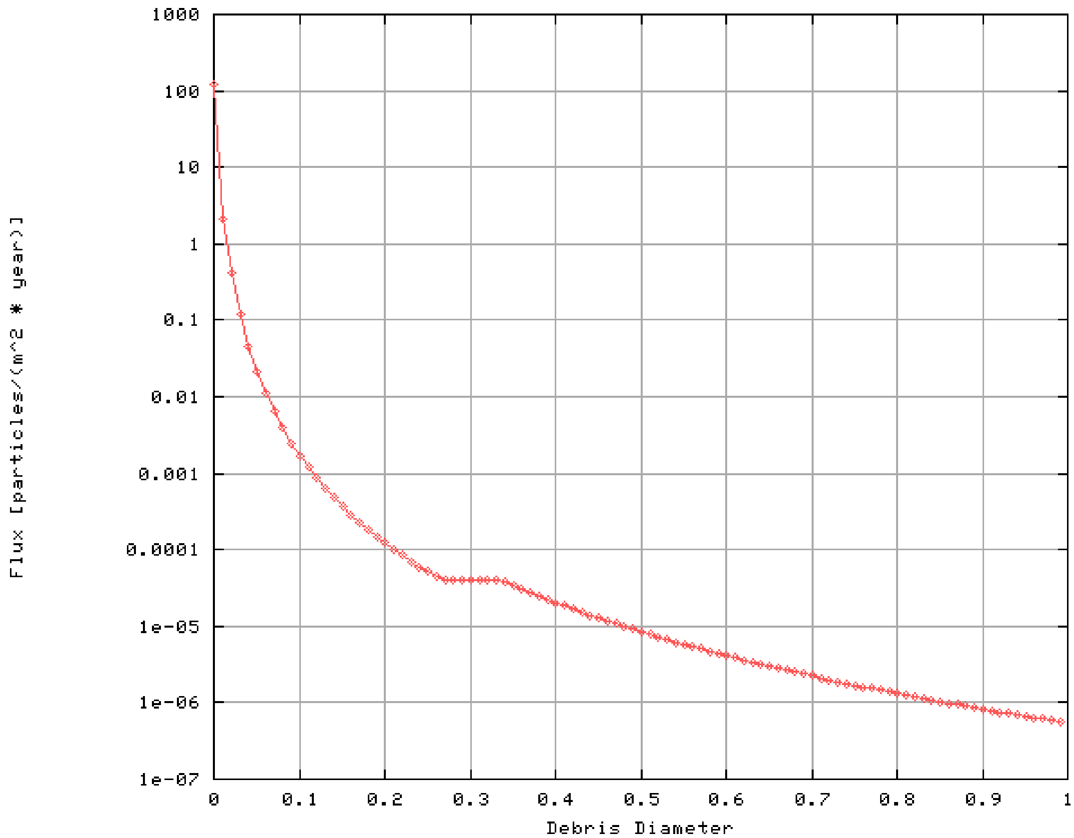


Figure 3-11. Meteoroid Environment at 550 km. Debris Diameter is in cm.

3.3.6.2.2 Debris Flux

Figure 3-12 gives the debris flux at 550 km. The orbital debris environment is composed of residue from man-made satellites and launch vehicles. The average velocity for objects smaller than 1 centimeter is 10 km/sec, and the average mass density is 2.8 g/cm^3. This flux is from the Orbital Debris Model, also found at http://envnet.gsfc.nasa.gov. It was run with the following parameters:

Debris Diameter (cm) varied,
Altitude 550 km,
Inclination 28.5 degree,
Year 2005,
Traffic Growth Rate 5%,
Small Object Growth Rate 2%,
Solar Flux 147.13

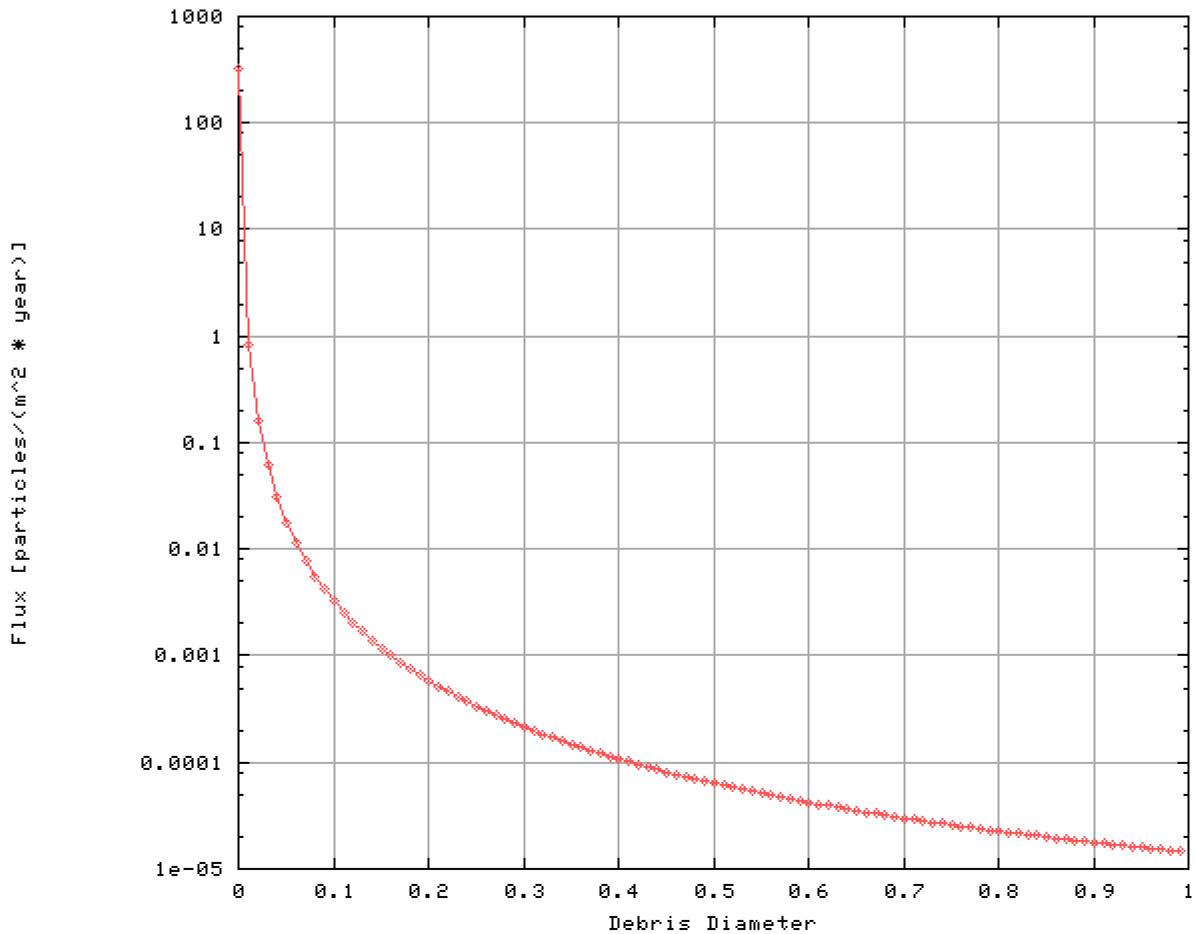


Figure 3-12. Debris Environment at 550 km. Debris Diameter is in cm.

3.4 Space-Ground Systems

3.4.1 General Requirements

3.4.1.1 Launch Readiness Date

The space-ground link shall support a launch readiness date as specified on the master schedule for the project.

3.4.1.2 In-Orbit Checkout

The space-ground link shall support an in-orbit checkout period of up to 60 days.

3.4.1.3 Operational Period

The space-ground systems shall support the GLAST operational lifetime of a minimum of 5 years, with a goal of 10 years, following an initial period of in–orbit checkout.

3.4.1.4 Orbit

The initial orbit altitude will be 550 km.
Orbit inclination will be equal to or less than 28.5 degrees.
Initial orbit eccentricity will be less than 0.01, as provided by the launch vehicle.

3.4.1.5 Data Standards

GLAST will employ the recommendations of the Consultative Committee on Space Data Systems (CCSDS) for the transport of its data through the space-ground links.

3.4.1.6 Grade of Service

3.4.1.6.1 Space-Ground Links

The space-ground links shall provide Grade-2 service as defined in the CCSDS Recommendation for Advanced Orbiting Systems.

3.4.1.6.2 Ground Links

Communication links between ground terminals shall provide the equivalent of CCSDS Grade-2 service.

3.4.1.7 Data Loss

3.4.1.7.1 Operator Error

The data loss allocated to the space-ground links for operator error shall not exceed TBD % of mission science data.

3.4.1.7.2 System Unavailability

The data loss allocated to unavailability of the space-ground link (downtime that causes a set of contacts to be missed) shall not exceed 0.1 % (TBR) of mission science data.

3.4.1.7.3 Transmission Losses

The data loss allocated to lost packets and errors that are tolerated in the space-ground downlink without retransmissions shall not exceed 0.2 % (TBR) of mission science data.

3.4.2 Global Positioning System

The GPS consists of the constellation of GPS satellites in 12-hour orbits and their master control center.
The GLAST system shall utilize the Standard Positioning Service of the Global Positioning System (GPS) to determine observatory position and time.

3.4.3 Space Network (SN)

3.4.3.1 Extended Operations

3.4.3.1.1 Non-routine Operations

The space network shall provide full-orbit coverage for S-band communications during launch and early orbit checkout and during contingency operations.

3.4.3.2 Unscheduled Communications

3.4.3.2.1 Target of Opportunity Transmission

The space network shall provide transmissions of targets of opportunity to the GLAST observatory from the MOC within 2 hours from receipt of request from the SSC.

3.4.3.2.2 Alert Transmission

The space network shall provide transmissions of alerts (celestial events and safe mode) from the GLAST observatory to the ground at any time during normal operations.

3.4.3.3 Communications Services

The space network shall provide the communications services at the rates and frequencies given in table 2.

3.4.4 Ground Network (GN)

3.4.4.1 Availability

3.4.4.1.1 Daily Access

During normal mission operations, a single GN station shall be available for contacts on at least 3 successive orbits every day.

3.4.4.1.2 Backup Response

At least one backup GN station shall be available within 6 to 12 hours of a problem with the primary station.

3.4.4.1.3 Contingency Standby

For checkout and contingencies, the GN stations shall be available for possible contacts on every orbit that is accessible to the respective ground station.

3.4.4.2 Automation

Each GLAST GN station shall be capable of operating with an unattended MOC.

3.4.4.3 Link Communications

3.4.4.3.1 S-Band/X-Band

Each GN station shall be equipped to provide simultaneous S-band and X-band support on the same contact.

3.4.4.3.2 Services

Each GN station shall communicate with the observatory at the data rates and frequencies given in Table 1.

3.4.4.3.3 Minimum Altitude Contacts

Each GN station shall be capable of acquiring a full contact of science data at altitudes as low as 350 km.

3.4.4.3.4 Data Handling Capacity

Each GN station shall be capable of handling at least one telemetry contact per day with up to 36 hours of science and housekeeping data generated at the orbit-average data rates.

3.4.4.3.5 Data Transmission Latency

Each GN station shall be capable of acquiring downlink science data and transmitting it to LIOC and MOC within 12 hours.

3.4.4.3.6 Data Buffering

The ground station shall buffer the most recent data for up to 7 days.

3.4.4.3.7 Data Retransmission on Ground

Upon request the ground station shall retransmit data within 7 days to the MOC or to LAT IOC.

3.5 Ground System Requirements

This section contains requirements that are common to the operating centers that comprise the ground system.

3.5.1 General Requirements

3.5.1.1 Ground System Architecture

The ground system consists of several interconnected operating centers, a Mission Operations Center (MOC), Instrument Operations Centers (IOC) for the LAT and for the GBM, and a Science Support Center (SSC). It is expected that the MOC will be a multi-mission operations center, while the other centers will be mission unique.

3.5.1.2 Security

The operations centers shall be interconnected by an intranet of wide area networks that is closed to, or protected from, public users of the external internet.

3.5.1.3 Autonomy

The ground system shall automatically transfer incoming downlink data, up to and including level zero data, between system elements

3.5.1.4 Software Environment

The ground system shall **support a single higher-level analysis software environment** (TBD) for use by the community and by the instrument teams.

3.5.1.5 Software Standards

The analysis environment shall **respect standards** that ensure software portability, independence of vendor, and compatibility with existing multi-mission high-energy astrophysics tools.

3.5.1.6 Launch Readiness Date

The ground system shall support a launch readiness date as specified on the master schedule for the project.

3.5.1.7 In-Orbit Checkout Period

The ground system shall support an in-orbit checkout period of up to 60 days.

3.5.1.8 Operational Period

The ground system shall support an operational lifetime of a minimum of 5 years, with a goal of 10 years, following an initial period of in–orbit checkout.

3.5.1.9 Orbit

The initial orbit altitude will be 550 km.
Orbit inclination will be equal to or less than 28.5 degrees.
Initial orbit eccentricity will be less than 0.01, as provided by the launch vehicle.

3.5.1.10 Coordinate Systems

The ground system shall use the J2000 inertial coordinate system, using RA and DEC, as a standard means of identifying and reporting celestial objects and of communicating pointing directions to the observatory.

3.5.1.11 Data Standards

The ground system shall employ the recommendations of the Consultative Committee on Space Data Systems (CCSDS) for telemetry and telecommand.

3.5.1.12 Units of Measurement

The ground system shall use metric units with the following exceptions: Angular measure may be expressed in degrees, minutes, and seconds; Photon and particle energy may be expressed in eV; and English units may be used for mechanical fabrication.

3.5.2 Ground System Functional Requirements

3.5.2.1 Observatory Operation

3.5.2.1.1 Basic Operation

The ground system shall utilize the basic operational modes of the observatory to acquire observational science data.

3.5.2.1.2 Reorientation for Downlink

The ground system shall reorient the observatory as needed to within the pointing envelope of the sky survey mode for downlink transmissions of science data.

3.5.2.1.3 Calibration Observations

The ground system shall use the observatory in pointed inertial mode to acquire observation data on known celestial sources.

3.5.2.1.4 LAT Unfiltered Observations

The ground system shall coordinate the acquisition of LAT unfiltered science data.

3.5.2.2 Basic Observations

3.5.2.3 Observatory Maintenance

The ground system shall maintain the observatory during its operational life.

3.5.2.3.1 Ground-Based Troubleshooting

The ground system shall be capable of resolving flight hardware and software faults and anomalies from the ground.

3.5.2.3.2 Software Loads

The ground system shall perform uploads of up to 1 MB of LAT or GBM flight software within 4 hours.

3.5.2.3.3 SAA Boundaries

The ground system shall maintain SAA boundary definitions during the course of the mission as a function of time and altitude.

3.5.2.4 Observing Plans

The ground system shall carry out the observing plans of GLAST investigators.

3.5.2.5 Data Handling

3.5.2.5.1 VCDU Service

The ground system shall accommodate the multiplexed virtual channel data unit (VCDU) service of the CCSDS Advanced Orbiting Systems Architectural Specification.

3.5.2.5.2 Telemetry Data

The ground system shall accommodate at least one telemetry contact per day that provides up to 36 hours of science and housekeeping data at the orbit-average data rates.

3.5.2.5.3 Packets

3.5.2.5.3.1 Variable Length

The ground system shall accommodate variable-length source packets for both science and housekeeping data.

3.5.2.5.3.2 Packetized Events

The ground system shall accommodate source packets that contain one or more gamma-ray events.

3.5.2.5.3.3 Ancillary Data

The ground system shall accommodate source data packets for science data that contain the ancillary data from the spacecraft.

3.5.2.5.3.4 Packet Identifiers

The ground system shall accommodate unique packet identifiers for each of the different sources of data (LAT, GBM, SC).

3.5.2.5.4 Data Loss

The data loss allocated to the operations centers for operator error shall not exceed TBD % of mission science data.

3.5.2.6 Data Processing

3.5.2.6.1 Minimum Processing Rate

The ground system shall process observation data at a rate that is no less than the orbit average rate at which it is acquired by the observatory.

3.5.2.6.2 LAT Unfiltered Data

The ground system shall be capable of processing LAT unfiltered science data.

3.5.2.7 Data Products

The ground system shall generate high-level data products (sky maps, source catalogs).

3.5.2.8 Targets of Opportunity

The ground system shall coordinate GLAST observations of gamma-ray bursts and other transients with other observatories.

3.5.2.9 Alerts

The ground system shall send alerts of gamma-ray bursts and other transients to other observatories.

3.5.2.10 Repointing Capability

The ground system shall be capable of ground-based repointing for gamma-ray bursts and other transients that are detected on board the observatory.

3.5.2.11 Archival Research

The ground system, in conjunction with the HEASARC, shall support archival research and multi-wavelength studies during, as well as after, the operation period of the mission.

3.5.2.12 Data Archives

The ground system shall permanently archive all mission data during and after the operational period of the mission.

3.5.3 External Interfaces

3.5.3.1 Space-Ground Link

3.5.3.1.1 MOC Interface

The MOC shall be the sole interface for commands between the elements of the ground system and the space-ground communications links.

3.5.3.1.2 Communications

The ground system shall communicate with the observatory via the space-ground link using the communication modes and data rates given in tables 1 and 2.

3.5.3.2 GPS

The ground system shall be capable of determining observatory orbit independently from GPS data in observatory telemetry data.

3.5.3.3 GCN

The ground system shall interface with the Gamma-ray burst Coordinates Network for communications of alerts of celestial events with other observatories.

3.5.3.4 HEASARC

The ground system shall interface with the High Energy Astrophysics Science Archive Research Center (HEASARC) in support of multi-wavelength studies.

3.5.3.5 External Users

The ground system shall interface with GLAST investigators via the commercial internet.

The ground system shall provide access to GLAST data that is made public via the commercial internet.